

Ross Sea polynyas: Response of ice concentration retrievals to large areas of thin ice

R. Kwok,¹ J. C. Comiso,² S. Martin,³ and R. Drucker³

Received 12 October 2006; revised 5 February 2007; accepted 8 March 2007; published 21 December 2007.

[1] For a 3-month period between May and July of 2005, we examine the response of the Advanced Microwave Scanning Radiometer (AMSR-E) Enhanced NASA Team 2 (NT2) and AMSR-E Bootstrap (ABA) ice concentration algorithms to large areas of thin ice of the Ross Sea polynyas. Coincident Envisat Synthetic Aperture Radar (SAR) coverage of the region during this period offers a detailed look at the development of the polynyas within several hundred kilometers of the ice front. The high-resolution imagery and derived ice motion fields show bands of polynya ice, covering up to $\sim 105 \text{ km}^2$ of the Ross Sea, that are associated with wind-forced advection. In this study, ice thickness from AMSR-E 36 GHz polarization information serves as the basis for examination of the response. The quality of the thickness of newly formed sea ice ($< 10 \text{ cm}$) from AMSR-E is first assessed with thickness estimates derived from ice surface temperatures from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument. The effect of large areas of thin ice in lowering the ice concentration estimates from both NT2/ABA approaches is clearly demonstrated. Results show relatively robust relationships between retrieved ice concentrations and thin ice thickness estimates that differ between the two algorithms. These relationships define the approximate spatial coincidence of ice concentration and thickness isopleths. Using the 83% (ABA) and 91% (NT2) isopleths as polynya boundaries, we show that the computed coverage compares well with that using the estimated 10-cm thickness contour. The thin ice response characterized here suggests that in regions with polynyas, the retrieval results could be used to provide useful geophysical information, namely thickness and coverage.

Citation: Kwok, R., J. C. Comiso, S. Martin, and R. Drucker (2007), Ross Sea polynyas: Response of ice concentration retrievals to large areas of thin ice, *J. Geophys. Res.*, 112, C12012, doi:10.1029/2006JC003967.

1. Introduction

[2] Even though the spatial resolution is fairly coarse, the great strength of the satellite passive microwave ice concentration records is its coverage and the length of the data record. For the combination of the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I), this spans over 25 years. The gridded fields of ice concentration from the Bootstrap (BBA) and NASA Team (NT) algorithms have contributed to a multidecade record that highlights the decline in Arctic Ocean sea ice coverage [Parkinson *et al.*, 1999; Comiso, 2002] and the need for understanding the role of sea ice in polar and global climates.

[3] Since the May 2002 launch of the Advanced Microwave Scanning Radiometer-EOS (AMSR-E) on the Aqua platform, improved observations of the Arctic and Antarctic sea ice cover have been acquired. These data are expected to set new directions for polar climate data sets and to provide a baseline for evaluation of the quality and consistency of

historical satellite records. With the combined capability of SMMR and SSM/I, the AMSR-E instrument measures vertically and horizontally polarized radiances at 6.9, 10.6, 18.7, 23.8, 36.5, and 89.0 GHz at double the SSM/I spatial resolution [Comiso *et al.*, 2003]. The Enhanced NASA Team (NT2) and AMSR-E Bootstrap (ABA) sea ice algorithms employed for the new data set take advantage of the added channels and better resolution to produce fields of sea ice concentration. The NT2 algorithm uses the 89-GHz channels to correct for atmospheric effects and to reduce anomalies due to surface snow layering, particularly in the Antarctic, present in the lower frequency horizontally polarized data. The ABA uses the 6.9-GHz channels to reduce uncertainties in ice concentration retrieval due to temperature effects that may be associated with extremely cold surface ice conditions (with little or no snow cover). More detailed discussions of these algorithmic improvements are given by Comiso *et al.* [2003] and Markus and Cavalieri [2000]. The efficacy of these refinements is currently being validated through various studies and field programs [Meier *et al.*, 2004].

[4] This paper focuses on the response of these ice concentration algorithms to relatively large homogeneous areas of young and thin ice compared to the spatial resolution of these instruments. The results of this assessment should find applicability in the interpretation of ice concentration retrievals over active polynyas (areas of

¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA.

²Cryospheric Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, Maryland, USA.

³School of Oceanography, University of Washington, Seattle, Washington, USA.

combined open water and thin ice). *Martin et al.* [2004] argue that given the rapid formation of frazil and pancake ice with distance downwind from the coast, it is physically more realistic to consider polynyas as containing primarily thin ice with limited open water rather than as primarily open water. From a remote sensing perspective, thin ice has an emissivity signature that lies between the values for open water and those of first-year ice. At 37 GHz and for ice thicknesses greater than ~50 mm, the high reflectivity of the underlying water no longer contributes to the emitted radiation and subsequent emissivity changes at greater thicknesses arise primarily from changes in the distribution of brine in the uppermost ice layers [*Grenfell et al.*, 1992]. In fact, recent work by *Martin et al.* [2004] used these emissivity changes to determine the thickness of thin ice formed in polynyas. In satellite passive microwave ice concentration retrievals, because of the coarse resolution of current instruments, low concentrations of thin ice are difficult to identify and can be easily confused with mixtures of thick ice and open water. Conversely, large areas of thin ice with very little open water can be interpreted as areas of lower ice concentration. Observed increases in satellite retrievals of ice concentration are due to a combination of changes due to ice growth and to increasing ice concentration. Thus a better understanding of these retrievals would improve their utility in the remote sensing of large polynyas.

[5] Our approach in the characterization of the thin ice response is to examine the empirical relationship between the retrieved ice concentration, C , and thin ice thickness estimates, h , (i.e., $C = f(h)$) at two sites: the Ross Sea Polynya (RSP) and the Terra Nova Bay Polynya (TNB). The RSP, which forms in the Ross Sea to the east of Ross Island and adjacent to the Ross Ice Shelf (RIS) is the largest Antarctic polynya. These regions are ideal for the present analysis: the mean winter coverage of the RSP is about 25,000 km² and the TNB is about 3000 km² [*Martin et al.*, 2007]. At the AMSR-E spatial footprint, these polynyas provide a large number of homogeneous thin ice areas that are formed under similar conditions. Our approach is as follows. First, we use the ice thickness derived from MODIS ice surface temperature (IST) to assess the robustness of the suggested relationship between thin ice thickness and the 36 GHz V/H ratios [*Martin et al.*, 2004]. As clouds and the water vapor released from the polynya obscure the surface in the visible/infrared, only MODIS retrievals from clear days are used. Then we use the AMSR-derived ice thickness estimates to examine the interpretation of retrieved ice concentration within winter polynyas over three winter months in 2005. Use of the AMSR-E 36 GHz V/H versus thin ice thickness (0–10 cm) relationship is less restrictive than the use of MODIS because this passive microwave channel is relatively unaffected by the atmospheric ice and moisture.

[6] Section 2 describes the data set used in the analyses. Our assessment is restricted to the period from May through July 2005 for which we have near coincident Envisat, MODIS, and AMSR-E data. Section 3 describes the character of the Ross Sea polynyas during a 3-week period in June 2005 for which high-resolution

SAR imagery and ice motion are available for detailing the smaller-scale features and polynya dynamics. Section 4 reviews the method used to retrieve ice thickness retrieval from the MODIS IST. The relationship between thin ice thickness and the AMSR-E 36 GHz V/H ratio [*Martin et al.*, 2004, 2005] is reexamined within the context of the Ross Sea polynyas. The AMSR-E derived ice thickness is then used in section 5 as a basis for assessment of the behavior of the NT2 and ABA ice concentration retrievals in largely homogeneous thin ice regions. The last section summarizes the paper.

6. Conclusions

[35] The NT2 and ABA algorithms are the two operational algorithms employed by NASA to produce global sea ice concentration estimates from AMSR-E observations. These algorithms do not take into account the transient signature of thin ice, thus large errors can be expected for regions where substantial amounts of such ice are present. For the 3-month in May, June and July 2005, corresponding to a period with available SAR coverage, this note examines the response of the algorithms to extensive areas of thin ice in the Ross Sea polynyas. The thin ice estimates derived from an algorithm using the ratio of the 36-GHz 12.5-km resolution vertical and horizontal brightness temperatures [*Martin et al.*, 2004, 2005] serve as the basis of our assessment. In particular, for the several weeks when SAR data are available, we examine with higher spatial resolution the smaller-scale features and wind-forced advection of the Ross Sea Polynya.

[36] The effect of large areas of thin ice in lowering the ice concentration estimates from both the NT2 and ABA approaches is clearly demonstrated. In general, thin ice has an emissivity that lies between the values for open water and those of first-year ice; thus it has a significant effect on the retrieval if it covers a significant fraction of the footprint. The results show relatively robust relationships between NT2/ABA retrieved ice concentration, C , and thin ice thickness estimates, h (i.e., $C = f(h)$), at the Ross Sea Polynya (RSP) and the Terra Nova Bay Polynya (TNB) (Figure 6). While the two algorithms respond differently to thin ice, the results show that within bounds, they do so consistently and reproducibly as seen in the daily estimates and the monthly averages. These relations define the approximate spatial coincidence between ice thickness and ice concentration isopleths. An ice thickness of 10 cm corresponds to the 83% and 91% ice concentration estimates from the ABA and NT2. For polynyas, this suggests that the retrieved ice concentrations can be used as a proxy for thin ice thickness.

[37] Since the area covered by sea ice within the 10-cm thickness contour contains 90% of the polynya heat loss [*Martin et al.*, 2004], an immediate application of our results is in the calculation of the polynya coverage. Using the ice concentration proxy to define the 10-cm thickness contour, we demonstrate that the daily polynya areas computed using the 83% (ABA) and 91% (NT2) ice concentration isopleths compare well, with quantifiable uncertainties, with those derived directly from the thickness fields.